

“TILT FOCUS METHOD AND MECHANISM FOR AN OPTICAL DRIVE”

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CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is related to U.S. Patent Application Serial No. 09/315,398, filed May 20, 1999, entitled "Removable Optical Storage Device and System," U.S. Provisional Application Serial No. 60/140,633, filed June 23, 1999, entitled "Combination
10 Mastered and Writeable Medium and Use in Electronic Book Internet Appliance," U.S. Patent Application Attorney File No. 4154-3, filed September 10, 1999, entitled "Content Distribution Method and Apparatus," U.S. Patent Application Attorney File No. 4154-4, filed September 10, 1999, entitled "Writeable Medium Access Control Using a Medium Writeable Area," U.S. Patent Application Attorney File No. 4154-10, filed April 12, 2000, entitled
15 "Low Profile and Medium Protecting Cartridge Assembly," U.S. Patent Application Attorney File No. 4154-8, entitled "Miniature Optical Disk for Data Storage," and U.S. Patent Application Attorney File No. 4154-9-CIP, entitled "Low Profile Optical Head," all of which are incorporated herein by reference in their entireties.

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FIELD OF THE INVENTION

The present invention is directed generally to an optical disk drive and more specifically to a method and mechanism for positioning an optical pickup element in three dimensions relative to an optical disk. The invention may utilize single or multiple optical disks. In the case of a single disk, the disk may be removable or non-removable.

BACKGROUND OF THE INVENTION

Optical disk drives are ideally suited for use in personal electronic devices (PEDs). By way of example, optical disk drives may be advantageously utilized in PEDs such as digital cameras, music reproduction equipment, MP3 players, cellular telephones, dictating equipment and personal digital assistants such as microcomputers. In particular, as compared to magnetic disk drives, optical disk drives are superior in terms of storage capacity, power consumption and data transfer speed. As a result, they can be smaller in size and cost. To be practical in PEDs, however, the optical drives need to be substantially pocket sized (e.g., no more than about 100 mm in the largest dimension, but preferably no more than about 50 mm, and preferably having at least one cross section no more than about 100 mm by about 50 mm, preferably no more than about 75 mm by about 25 mm) and have a mass of no greater than about 1/3 kg.

Much of the development of optical disk data storage has centered around apparatus in which the read/write mechanism was configured to position a read/write beam at a desired radial location on the disk in a substantially linear fashion (i.e., linear actuators). Typically, a sled carrying an objective lens moves radially along a pair of rails between the inside and outside diameter of a disk for course tracking purposes. A second mechanism or linkage is mounted in the sled and rotates the objective lens in an arcuate path for fine tracking purposes. Further structure also moves the objective lens orthogonally relative to the disk surface for purposes of adjusting the focus of the light beam on the data layer of the disk. While linear actuators have proved useful in a number of contexts, such as for reading/writing CDs and DVDs, the location and mass of the components in linear actuators

has typically affected performance parameters such as access time, data transfer rates, and the like. In addition, linear actuators are relatively high-friction devices and require precise track alignment. Linear actuators typically add substantial thickness to a read/write or drive device and generally do not scale well toward miniaturization. Also, linear actuators are typically unbalanced systems in that the mass of the components, including the objective lens, is not evenly distributed relative to any pivot point. As a result, such actuators are highly susceptible to shock and vibration. Thus, linear actuators have, in general, found greatest use in applications where thickness, access time, bandwidth and power consumption are of less importance, and typically are used in larger stationary devices where space for moving the read/write head is available and the risk of shock or significant vibration is minimized.

Another factor affecting the size of an optical system is the size and shape of the light beam as it reaches the optical disk (the spot size and quality). Spot size and quality is, in turn, affected by a number of factors including, the size of the optical components, relative movement among the optical components, the distance the light beam must travel and the format of the optical disk. Although a wide variety of systems have been used or proposed, typical previous systems have used optical components (such as a laser source, lenses and/or turning mirrors) that were sufficiently large and/or massive that functions such as focus and/or tracking were performed by moving only some components of the system, such as moving the objective lens (e.g. for focus) relative to a fixed light source. However, relative movement between optical components, while perhaps useful for accommodating relatively large or massive components, presents certain disadvantages, including a relatively large

form factor and the engineering and manufacturing associated with establishing and maintaining optical alignment between moveable components. Such alignment often involves manual and/or individual alignment or adjustment procedures which can undesirably increase manufacturing or fabrication costs for a reader/writer, as well as contributing to costs of design, maintenance, repair and the like. Accordingly, it would be useful to provide an optical head method, system and apparatus which can reduce or eliminate the need for relative movement between optical components during normal operation and/or can reduce or eliminate at least some alignment procedures, e.g., during reader/writer manufacturing.

In order to adequately miniaturize the mechanics associated with an optical disk drive for use in a commercially acceptable PEDs, the optical recording system's focus of the laser spot on the recording and playback surface must be maintained to assure acceptable recording and playback data integrity. In general terms, an objective lens directs a light beam to the optical disk and focuses the light beam into a conical shape with the apex or focal spot occurring at the data layer within the optical disk. Ideally, the conical beam is perpendicular to the surface of the disk, although, given irregularities in the manufacture of the disk and its component layers (i.e. disk flatness), bearing defect frequencies, and tolerances in the manufacture and assembly of the mechanical components, as well as shock and vibrations imparted into the disk drive during operation, perpendicularity between the disk surface and light beam is difficult to maintain. The distance between the objective lens and the data layer determines the particular characteristics which the objective lens must possess. For example, the farther the data layer of the disk is from the objective lens, the

larger the objective lens must be in order to focus the light beam into the proper conical shape with the focal spot at or proximate to the data layer. In turn, as the objective lens increases in size in order to form the appropriately sized light beam, the other optical components must also increase in size in order to complement each other. Thus, for
5 miniaturization purposes, it is critical to minimize this distance between the objective lens and the data layer on the disk.

A significant factor in reducing the distance between the objective lens and the data layer of the optical disk is the characteristics of the disk itself. Optical disks used in consumer products today typically utilize second surface optical media as opposed to first
10 surface optical media. In the preferred embodiment of the present invention, the optical medium is first-surface media. Although it may be subject to more than one definition, first-surface optical media refers to media in which the read beam during a read operation is incident on or impinges on information content portions of the first-surface optical media before it impinges on a substrate of the first-surface optical media. The information content
15 portions can be defined as portions of the optical media that store or contain servo data, address data, clock data, user data, system data, as well as any other information that is provided on the optical media. The information content portions can be integral with the substrate such as the case of a read-only media. The information content portions can also be separately provided. In such a case, the information content portions can be, for example,
20 an information layer of a writeable media. Stated conversely, second-surface media can refer to media in which the read beam is incident on the surface of the media or disk before it is incident on the information content portions.

A relatively thick and transparent outer layer or substrate of second-surface optical medium makes read-only or read-write operations relatively insensitive to dust particles, scratches and the like which are located more than 50 wavelengths from the information content portions. Considering the cone angle of the light beam after the light beam passes through the objective lens, there is also little detrimental change to the shape or power of the light spot by the time it reaches the information layer of this second-surface optical medium. On the other hand, the second-surface optical medium can be relatively sensitive to various optical aberrations. These optical aberrations include: (1) spherical aberrations - a phase error causing rays at different radii from the optic axis to be focused at different points; (2) coma - creating a "tail" on the recorded spot when the transparent layer is not perpendicular to the optical axis; (3) astigmatism - creating foci along two perpendicular lines, rather than a symmetric spot; and/or (4) birefringence - different polarizations of light behave differently because the read-only or read-write beam must propagate through a relatively longer distance before reaching the information layer, when an aberration is created at the air/transparent layer interface. This longer distance is attributable to the thickness of the relatively thick transparent substrate or layer. Compounding the unwanted birefringence is the requirement that the read-write beam must also traverse the transparent layer again after reflection.

Some or all of the aberrations arising from the presence of the thick transparent layer can, at least theoretically, be partially compensated for by using a suitable focus mechanism. However, such a focus mechanism, including the optical elements thereof, tends to be large in size and, concomitantly, increases the cost of the system. Additionally, such a focus mechanism typically can only provide compensation for a single, pre-defined thickness of

the layer. Because there are likely to be spatial variations in the thickness or other properties of the transparent layer, such compensation may be less than desired at some locations of the medium.

Another drawback associated with second-surface optical media is that the optical requirements of such media are substantially inconsistent with the miniaturization of the disk drive and optical components for such media. As will be appreciated by reference to Fig. 1A, a longer focal length "f" is required for an optical system that will read information from or write information onto second-surface media. This is due to the relatively thick transparent layer "T" through which the radiation must pass to access the recording or data layer "D." To provide the longer focal length a larger beam cone is required which, in turn, requires larger optical components (e.g., objective lens "O"). Moreover, the relatively long optical path through the thick transparent layer to the data layer and back through the transparent layer after reflection significantly decreases laser power efficiency in comparison to a medium without the transparent layer. In comparison, as shown in Fig. 1B, a shorter focal length "f" can be achieved by utilizing first surface recording instead of second surface recording. Importantly, a smaller focal distance "f" allows use of a smaller objective lens "O." This in turn allows the other optical components to be reduced in size thereby facilitating overall miniaturization.

To date, rotary actuators have not provided a solution to miniaturization in optical disk drives either. Like linear actuator systems, rotary actuator systems are subject to the same problems created by imperfections in the manufacture of disks, mechanical tolerances in the manufacture and assembly of the actuator arm and spindle, bearing defect frequencies,

shock and vibration, among others. As a result, the data surface may be out of focus at any point in time, creating errors in reading from or writing to the disk. As stated earlier, optical drives have attempted to address this problem by moving the objective lens orthogonal to the ideal or presumed plane of the disk surface to change its focal length, and thereby attempt to maintain focus. This methodology has limited effectiveness. For example, in larger disks, such as DVDs and CDs, errors or fluctuations are compounded as the objective lens moves toward the outer diameter of the disk. Thus, in order to try to maintain focus, the objective lens is required to move a greater distance away from or toward the disk surface (in the Z direction). However, the necessary range of movement in a miniaturized system would likely be constrained by space limitations and/or physical limits purposefully placed in the drive to limit movement. In unbalanced systems in particular, such physical limits are required to prevent linkages from moving past their elastic limits, primarily due to external shock.

SUMMARY OF THE INVENTION

The focus mechanism of the present invention solves many of the miniaturization problems associated with previous optical disk drive systems. The present invention comprises a rotary actuator having a tracking arm for movement of an optical pick up unit generally parallel to the disk surface and a focus arm for movement generally perpendicular to the disk surface. The focus arm may be balanced or unbalanced, although a balanced system is preferred in order to best handle shock and vibration. The optical pick up unit is supported at the distal end of the focus arm. In the preferred embodiment, the optical pick

up unit includes a light source, such as a laser, an objective lens for directing the light beam to the recording/playback surface of the disk and intermediate optical components such as turning mirrors and focusing lenses. The light beam is folded utilizing turning mirrors to achieve a length that is compatible with a chosen objective lens. The optical pickup unit achieves further miniaturization when used in combination with media utilizing first surface data, although it will also work with second surface media. In the context of first surface data, the objective lens can be smaller because the information containing portion or data layer is closer to the objective lens which allows use of a lens with a shorter focal length.

The tilt focus method of the present invention also introduces an out-of-perpendicular condition for the laser beam for purposes of maintaining the focus of the light beam on the data layer of the disk. Rotation of the focus arm relative to the tracking arm moves or pivots the focus arm which also moves the optical pick up unit, including the objective lens. In general terms, the optical pick up unit will move in an arcuate or curved path toward or away from the surface of the disk, although the directional component of movement orthogonal to the disk surface is substantially greater than the directional component of movement parallel to the disk surface. This is true for each of the embodiments described herein, except one, even though the magnitude of movement in each of the component directions may vary among embodiments. In the third principal embodiment described herein, the optical pick up unit does not move in an arcuate path. For purposes of this patent, however, the terms perpendicular or substantially perpendicular will be used to refer to movement of the optical pick up unit in each embodiment.

By dynamically adapting the position of the objective lens during operation of the drive, the system can respond to variations in the relative position of the data layer caused by imperfections in the manufacture of the disk, manufacture and assembly tolerances of component parts, bearing defects, spindle motor run out, shocks, vibrations and other conditions that cause misalignment of the light beam relative to data on the disk. In this manner, the present invention will overcome conditions that could otherwise result in read/write errors.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1A is a cross-sectional schematic view of a linear actuator and light beam focused on a non-first surface data layer.

Fig. 1B is a cross-sectional schematic view of a linear actuator and light beam focused on a first surface data layer.

Fig. 2 is a three-quarter perspective view of an optical disk drive of the present invention.

Fig. 3 is a three-quarter perspective view of a first embodiment of a tilt focus mechanism of the present invention.

Fig. 4 is an exploded view of the component pieces of the tilt focus mechanism shown in Fig. 3.

Fig. 5 is a three-quarter perspective view of the tracking arm of the tilt focus mechanism shown in Fig. 3.

Fig. 6 is a three-quarter perspective view of the focus arm of the tilt focus mechanism shown in Fig. 3.

Fig. 7 is a three-quarter perspective view of the tracking arm and focus arm of the tilt focus mechanism shown in Fig. 3.

5 Fig. 8 is a cross-sectional view of the tilt focus mechanism shown in Fig. 3.

Fig. 9 is a three-quarter perspective view of the flex circuit, optical pick up unit and heat sink of the tilt focus mechanism of Fig. 3.

Fig. 10 is a cross-sectional view of a disk drive showing the tilt focus mechanism of Fig. 3, with the objective lens in a normal position relative to the optical disk.

10 Fig. 11 is a cross-sectional view of an optical disk drive containing the tilt focus mechanism of Fig. 3, further showing the objective lens pivoted .6 degrees closer to the optical disk.

Fig. 12 is a cross-sectional view of an optical disk drive containing the tilt focus mechanism of Fig. 3, further showing the objective lens pivoted .6 degrees away from the
15 optical disk.

Fig. 13 is a three-quarter perspective view of a tracking arm and focus arm of a second embodiment of the tilt focus mechanism of the present invention.

Fig. 14 is an exploded perspective view of the tracking arm of the embodiment shown in Fig. 13.

20 Fig. 15 is an exploded perspective view of the focus arm of the tilt focus mechanism shown in Fig. 13.

Fig. 16 is a three-quarter perspective view of a third embodiment of the tilt focus mechanism of the present invention.

Fig. 17 is an exploded view of the tilt focus mechanism shown in Fig. 16.

Fig. 18 is a three-quarter perspective view of the tracking arm of the tilt focus
5 mechanism shown in Fig. 16.

Fig. 19 is a three-quarter perspective view of the focus arm of the tilt focus mechanism shown in Fig. 16.

Fig. 20 is a three-quarter perspective view of the fine actuator of the tilt focus mechanism shown in Fig. 16.

Fig. 21 is a three-quarter perspective view of the flex circuit of the tilt focus
10 mechanism shown in Fig. 16.

Fig. 22 is a three-quarter perspective view of the suspension assembly for the tilt focus mechanism of the embodiment shown in Fig. 16.

Fig. 23 is a three-quarter perspective view of a fourth embodiment of the tilt focus
15 mechanism of the present invention.

Fig. 24 is an exploded view of the tilt focus mechanism shown in Fig. 23.

Fig. 25 is a three-quarter perspective view of the tracking arm and focus arm of the tilt focus mechanism shown in Fig. 23.

Fig. 26 is a three-quarter perspective view of the flex circuit, optical pick up unit and
20 heat sink of the tilt focus mechanism shown in Fig. 23.

Fig. 27 is an exploded perspective view of an alternative embodiment of the actuator arm of Fig. 23.

light beam (not shown), such as a laser, to the optical disk which is spinning at a rapid rate. The light beam may be used to write information to the disk or may be used to read information resident on the disk. Because information is stored on the disk in tracks, typically concentrically arranged, the optical pick up unit (OPU) 22 must be able to traverse
5 the surface of the disk from the inside to the outside diameter in order to access the information formatted on the disk, whether in tracks or not. To accomplish this, the tilt focus mechanism 10 moves in three directions relative to the surface of the optical disk. Generally, the tilt focus mechanism 10 moves laterally across the disk surface for tracking purposes, which can be defined as the X-Y plane for convenience purposes, and it also moves toward
10 and away from the disk surface for focusing purposes, which can be defined as the Z direction for convenience purposes. In this manner, as explained in greater detail below, the tilt focus mechanism 10 can compensate for imperfections in the optical media and read and write data to and from the optical disk more accurately and faster than existing optical drives or magnetic drives.

15 As shown in Figs. 3-8, a first embodiment of the tilt focus mechanism 10 comprises a tracking arm 24 and a focus arm 26 disposed on the distal end of the tracking arm 24. Rotary motion is imparted to the tracking arm 24 by means of a voice coil motor (VCM) 28. More specifically, the tracking arm 24, shown separately in Figs. 4 and 5, includes a central bearing mounting bore 30 which receives a bearing cartridge 32. The bearing cartridge 32
20 pivots about a fixed shaft 34 mounted between the tracing VCM return plate 36 and a voice coil motor magnet plate 38. The tracking arm 24 further includes a wire coil 40 wound around a bobbin 42 and adhered between a pair of rearwardly extending support arms 44, 46

of the tracking arm 24 with an adhesive 48. By directing a current through the wire coil 40 a magnetic field is created which interacts with the magnetic fields surrounding a pair of permanent tracking magnets 50, 52 (shown in Figs. 2 and 4), forcing the tracking arm 24 to pivot about the shaft 34. It should be appreciated that the relative positions of the permanent tracking magnets 50, 52 and the wire coil 40 may be switched, with the coil 40 being stationary and the magnets 50, 52 affixed to and moving with the tracking arm 24.

The focus arm 26 is mounted to the distal end of the tracking arm 24. A counterweight 54 is typically affixed to the end of the tracking arm 24 for purposes of counterbalancing about the shaft 34 the weight of the focus arm 26 components on the opposite end of the tracking arm 24. The OPU 22 is positioned on the distal end of the focus arm 26 between a pair of support arms 56, 58. The purpose of the focus arm 26 is to move the OPU 22 toward and away from the disk surface, in the Z direction. A focus bearing assembly 60, mounted in the tracking arm 24, cooperates with a shaft 62 to allow the focus arm 26 to rotate relative to the tracking arm 24 and the disk surface (i.e., in the Z direction). The shaft 62 mounts in a pair of focus bearings 64 which, in turn, are mounted in a pair of pivot bearing supports 66, 68 in the focus arm 26.

Movement of the focus arm 26 relative to the tracking arm 24 is created by a second voice coil motor (VCM) 70 (Fig. 4). As best seen in Figs. 5-8, a voice coil motor frame 72 is disposed at the forward end of the tracking arm 24. A pair of permanent magnets 74, 76 are mounted to the VCM frame 72. A focus coil 78, attached to the focus arm 26, is positioned adjacent each of the permanent magnets 74, 76 with the center arm 75 of the VCM frame 72 positioned in the open center area of the focus coil 78. A spacer 80 may be

included to optimize the position of the focus coil within the magnetic field created by the magnets 74, 76. By inducing a current in the focus coil 78, the focus arm 24 will pivot in the Z direction about the bearing assembly 60 relative to the tracking arm 24 (perpendicular to the surface of the disk). A counterweight 82 is positioned at the distal end of the support arms 56, 58 to balance the weight of the focus arm 26 and its components about the shaft 62. It should be appreciated, however, that the relative position of the counterweight 82 and VCM 70 can be switched and the same results achieved. As a result of the balanced nature of the focus arm 26, the VCM 70 can more easily adjust the position of the focus arm 26 to focus the objective lens relative to the data surface of the disk. In addition, a key advantage of a balanced focus arm is its ability to withstand substantially larger shock and/or vibration forces than an unbalanced arm, without incurring a position error of the OPU 22 relative to the data track.

A flex assembly or flex circuit 84 is affixed to the tracking arm and focus arm to carry signals between the OPU 22 and appropriate processors mounted on a printed circuit board and maintained in the housing 14 of the optical drive. Two different embodiments of the flex assembly 84 are shown in the drawings with this embodiment. As shown in Figs. 3 and 9, a first version of the flex circuit 84 is mounted to a bracket 86 affixed to the tracking arm 24 and is positioned along one side of the focus arm 26, attaching to the underneath side of the focus arm 26 at its distal end. Alternatively, as shown in Figs. 4 and 13, the flex circuit 84 includes a rectangular bracket 86 which is positioned along both sides of the focus arm 26. Both flex circuits 84 are designed to pivot in all three directions of movement of the tilt focus mechanism 10 so as not to inhibit movement of the tilt focus mechanism. A heat

sink 88 may be included in either version at the location where the OPU 22 attaches to the flex circuit 84 to facilitate dissipation of heat generated by the operation of the laser resident in the OPU 22.

In operation, servo information embossed or otherwise residing in the data layer of the optical disk is monitored by the optical pick up unit 22 and sent to appropriate processors over the flex cable 84. Based upon the servo information, a processor (not shown) directs current to flow through coil 40 thereby creating a magnet field which induces movement of the tracking arm 24. The magnitude of the movement of the tracking arm is controlled by a processor. In this manner, the tracking arm 24 can move the OPU 22 across the entire disk surface to move from one track to another or can minimally adjust the position of the OPU 22 to maintain its position over a desired track. In other words, the tracking arm 24, including VCM 28, provides single stage tracking, i.e., both coarse and fine tracking.

In comparison, VCM 70 similarly adjusts the position of the OPU 22, but in a direction substantially perpendicular to the disk surface. This orthogonal component of this movement repositions the OPU 22 and its objective lens 90 to accommodate for disk flatness, variations in thickness in the disk layers, vibrations imparted into the system by the various motors, bearing defects, spindle motor run out and any other imperfections that can lead to orthogonal misalignment of the OPU 22 relative to the data tracks. For example, if the disk is created in such a manner that the surface of the data layer fluctuates, the optical feed back to the processors can sense a change in the quality of the light beam and adjust the position of the OPU 22 using VCM 70 to correct for misalignment between the OPU 22 and the data layer. These adjustments are made dynamically to thereby decrease read/write errors

and enhance performance. This adjustment is illustrated in Figs. 10-12 which provide a cross-sectional view of the tilt focus mechanism 10. Fig. 10 shows the optical drive with the OPU 22 in its normal position, with the objective lens 90 perpendicular to the surface of the disk "D." Fig. 11 shows the focus arm 26 repositioned such that the objective lens 90 is rotated 0.6 degrees closer to the disk drive surface. As a result, the spacing between the objective lens 90 and the surface of the disk "D" is decreased. Conversely, Fig. 12 shows the focus arm 26 repositioned with the objective lens 90 0.6 degrees further away from the surface of the disk "D." Thus, the range of movement of the focus arm allows the objective lens to maintain the light beam in a focused condition through a range of 1.2 degrees of movement thereby compensating for imperfections in the disk, the manufacture and assembly of the drive components and external shock or vibration. It should be appreciated that the range of motion can be increased or decreased and that the present invention is not limited to this particular embodiment or range of motion. The size of the objective lens and its focal length are an important factor in determining the amount of deviation from perpendicular that any system can accommodate.

A variation of the foregoing embodiment is illustrated in Figs. 13-15. In this embodiment, the VCM 70 utilizes a single permanent magnet 74. As a result, the VCM frame 72 is smaller and lighter in weight. Because of its lighter weight, the components of VCM 28 can be made smaller, as less torque is required to move the tilt focus mechanism 10. More specifically, the coil 40 and bobbin 42 may be made smaller, as can the rear end of the tracking arm 24 supporting the VCM 28. With less mass, the counterweight 54 may also be smaller. A lighter weight and smaller tilt focus mechanism 10 will achieve faster

seek times and be more accurate. It will also be more compact, allowing further miniaturization. As with the previous embodiment, the general location of the counterweight 54 and VCM 70 may be switched.

A third embodiment of the present invention is shown in Figs. 16-22. In general, this embodiment includes a tracking arm 100 for course movement in the X-Y direction (parallel to the surface of the optical disk) and a focus arm 102 for fine tracking and for focus movement in the Z direction (perpendicular to the disk surface). Thus, unlike the tracking arm 24 in the first two embodiments, tracking is accomplished by two stages rather than one. Like the tracking arm 24 in the first two embodiments, the tracking arm 100 includes a bearing mount bore 104 for receiving a bearing cartridge 106 which allows the tracking arm 100 to pivot about a shaft 108 mounted between a tracking VCM return plate and a VCM magnet plate (not shown) of the optical drive. As should be appreciated by one skilled in the art, as an alternative, the shaft 108, in this embodiment or in any of the disclosed embodiments, may be fixed or stationary. A coil 110, wound around bobbin 112, is mounted between a pair of support members 114, 116 at the rearward end of the tracking arm 100, together with the counterweight 118. Magnets (not shown) are positioned adjacent the coil 110 to form a voice coil motor to provide a directional torque based upon the direction of current induced in the coil 110 to move the tracking arm 100 relative to the surface of the optical disk. It should be appreciated that the coil 110 may be stationary and the magnets may be positioned on the tracking arm 100 and move with the tracking arm.

As best seen in Fig. 22, a suspension member 116 for supporting and positioning the focus arm 102 comprises a cylindrical yoke 120 with two shoulders 122, 124 extending

outwardly from the yoke 120 in opposite directions. The bearing assembly 106 fits inside the open center 126 of the yoke 120. Two pair of parallel support wires 128, 130 extend forward from the suspension member 116 and terminate in a pair of front suspension mounts 132, 134. The support wires are enlarged at location 136 (on the top and bottom surfaces of the yoke 120 and front suspension mounts 132, 134) to facilitate stability and mounting between the support wires 128, 130, the yoke 120 and the forward suspension mounts 132, 134. The focus arm 102 attaches to the front suspension mounts 132, 134 and moves relative to the tracking arm 100 by a flexing of the suspension wires 128, 130. Unlike the previously discussed embodiments, the present embodiment of the focus arm is unbalanced and, therefore, the focus arm 102 is subject to constant adjustment in order to maintain proper position. Such constant adjustment can drain power, particularly if the weight of the components of the focus arm 102 is not minimized. Also, as an unbalanced member, it is more susceptible to misalignment errors created by shock or vibration. It may therefore be advisable to place physical limits on the range of movement of support wires 128, 130 to prevent them from moving past their elastic limit as a result of an external shock.

The focus arm 102 is moved relative to the tracking arm 100 by a hybrid pair of voice coil type motors for both fine tracking and focus of the OPU 138 disposed at the end of the focus arm 102. A fine positioning actuator 140 is mounted between the front suspension mounts 132, 134. The fine actuator 140 includes a forward portion 142 with a cutout 144 for housing the OPU 138. Fine tracking coils 146, 148 are positioned between a pair of rear suspension arms 150, 152 of the fine actuator 140. A focus coil 154 is positioned perpendicular to and within the center cavity 156, 158 of the fine tracking coils 146, 148.

The fine tracking coils 146, 148 and focus coil 154 coact with a pair of permanent magnets 160, 162 mounted to the tracking arm 100 (Fig. 18). The tracking arm 100 also includes a pair of VCM end returns 164, 166, a center return 168 and a top plate 170 to create a magnet flux path in association with the hybrid voice coil motor. It should be appreciated, as a further alternative, that the coils 146, 148 and 156 could be mounted on the tracking arm 100 and the magnets 160 and 162 positioned on the fine actuator 140.

A flex circuit 172, shown in Fig. 21, provides a communication path between the OPU 138 and the drive processors (not shown). In addition, a heat sink 174 may be added to facilitate removal of heat generated by the laser within the OPU 138, as well as due to constant positioning of the fine actuator 140 for focusing, fine tracking and positioning of the objective lens 176.

Applying a current to the fine tracking coils 146, 148 creates a force on the focus arm 102 generally parallel to the disk surface, i.e. in the X-Y plane. This causes the support wires 128, 130 to bend sideways or laterally, moving the OPU 138 and objective lens 176 generally parallel to the disk surface for fine tracking purposes. The flex circuit 172 includes flat portions 178, 180 which accommodate bending in the X-Y direction. Applying a current to the focus coil 154 will create a force which moves the OPU 138 in a direction generally perpendicular to the disk surface, i.e. in the Z direction. As compared to the other embodiments described herein, the four bar linkage created by support wires 128, 130 will tend to maintain the objective lens perpendicular to the surface of the disk, rather than move the objective lens through an arcuate path. Flat portions 182, 184 of the flex circuit 172 bend

in response to the force created by the focus coil 154. This movement allows the OPU 138 and objective lens 176 to move and maintain focus.

A fourth embodiment is disclosed in Figs. 23-29. In general, this embodiment comprises a single actuator arm 200 having a bearing bore mount 202 which mounts to a bearing cartridge 204. The bearing cartridge 204 is rotatably connected to a shaft 206 mounted between a tracking VCM return plate 208 and the cover or a similar cap structure (not shown). For coarse and fine tracking purposes, the actuator arm 200 moves in a conventional manner responsive to torque induced by VCM 210. The VCM 210 comprises a coil 212 wound around a bobbin 214 placed within a pair of arms 216 and 218 at the rear end of the actuator arm 200. Permanent magnets 220 and 222, in cooperation with alternating current flowing in the coil 212 and the return path provided by tracking VCM return plate 208 and tracking VCM magnet plate 224, create the necessary torque to pivot the actuator 200 about the shaft 206. The tracking VCM magnet plate 224 further includes an aperture 226 to provide clearance for the shaft 206 and bearing cartridge 204 to be secured between the VCM return plate 208 and the cover. As will be appreciated, the components of the VCM 210 may be switched relative to each other such that the coil 212 is stationary and the magnets 220, 222 move with the actuator arm 200.

This embodiment utilizes an unbalanced focus structure. The focus arm 228 of the actuator 200 includes a number of cutouts to lessen its weight. Additionally, a slot 230 at the distal end is adapted to receive OPU 232. Movement of the focus arm 228 of the actuator 200 in the Z direction (perpendicular to the disk surface) is accomplished by an integral flexure pivot 234 in the actuator 200 adjacent the bearing bore mount 202. It should be

understood, however, that the flexure need not be integral to the actuator 200, but may be a separate piece or layer in a laminated composite structure. For example, the laminate structure may comprise a carbon fiber composite upper layer 231, a metal center layer which includes the flexure 233, and a carbon fiber layer 235, as shown in Figs. 27-29.

5 A focus VCM 236 acts to move the focus arm 228 of the actuator 200 (the focus arm) in the Z direction. The VCM 236 comprises a coil 238 mounted to the focus arm 228. The shape of the coil 238 forms a channel 240 which surrounds a permanent magnet 242 mounted within a VCM block 244. More specifically, the permanent magnet 242 is positioned within a slot 246 formed in the VCM block 244. However, it should be
10 appreciated that the shape of the coil may vary without effecting operation. For example, the coil 238 may be flat, i.e. two dimensional, rather than the three dimensional structure shown. The outer walls 248 and 250 of the VCM block 244 create the return path for the magnetic flux, allowing the focus arm 228 to move perpendicular to the surface of the disk as the overall actuator arm 200 moves parallel to the surface of the optical disk. In addition,
15 the coil 238 may be stationary and the magnet 242 moves in association with the focus arm 228.

 In this unbalanced embodiment, the voice coil motor 236 is positioned at the center of percussion for the focus arm 228. It is advantageous to locate the voice coil motor of the focus arm at, or as near as possible to, the center of percussion for the overall focus arm in
20 any unbalanced embodiments, if possible. In this manner, the force generated by the focus arm VCM will minimize, or preferably eliminate, any detrimental excitation or resonance at the pivot point (i.e., flexure 234) for the focus arm which could otherwise negatively affect

focus. If the VCM 236 were not positioned at or near the center of percussion, the force placed on the focus arm 228 by the VCM 236 could generate forces at the pivot point 234 which would interfere with the positioning of the focus arm, thereby potentially creating focus errors and, therefore, inhibit the ability of the system to read and write. As used herein,
5 the term center of percussion is understood to have the meaning set forth in Mark's Standard Handbook for Mechanical Engineers (8th ed.), which is incorporated by reference.

A flex circuit 252, shown in Figs. 23, 24 and 25, attaches along one side of the actuator 200. A heat sink 254 is included to dissipate heat created by the laser (not shown) housed within the OPU 232. Thus, as with the other embodiments, the objective lens 256
10 may be repositioned in the orthogonal direction relative to the disk surface in order to maintain focus.

As will be appreciated, the integral flexure pivot 234 is only one structure that allows for movement of the focus arm 228 in a direction perpendicular to the surface of the optical disk. First, the structure need not be a single piece of material, but may be multiple or
15 separate pieces. Pivoting may be provided by any number of known mechanisms, including but not limited to a ball bearing pivot, a jewel bearing pivot, a knife edge pivot, or a torsional shear member pivot or any other type of pivot known by persons of skill in the art. While the various focus arms in the various embodiments illustrated herein can be lengthened to achieve a greater range of motion, the objective is to minimize the angular change of the
20 objective lens for any given range of motion of the focus arm in the Z direction. This embodiment allows for the greatest range of movement of the objective lens with the least perpendicularity error.

A fifth embodiment of the tilt focus mechanism 10 of the present invention is shown in Figs. 30-35. As can be seen in Fig. 30, the tilt focus mechanism includes a tracking arm 300 and a focus arm 302. The tracking arm 300 is shown separately in Fig. 32 and the focus arm 302 is shown separately in Fig. 33, with the components of each shown in an exploded format in Fig. 31.

With reference to the tracking arm 300, a bearing bore mount 304 receives a bearing cartridge 306 which, in turn, mounts to a shaft 308. The shaft 308 is seated between a tracking VCM return plate 310 and a tracking VCM magnet plate 312. The rotational movement of the tracking arm 300 is provided by VCM 314, which includes a coil 316 wound around a bobbin 318. Permanent magnets 320 and 322, in combination with the VCM magnet plate 312, and return plate 310 and the coil 316, cause the tracking arm 300 to pivot about the shaft 308 and move the focus arm 302 parallel to the surface of the disk for coarse and fine positioning of the OPU 324 relative to the tracks in the optical disk.

In this embodiment, the focus arm 302 is balanced. As can be appreciated from Fig. 33, the VCM block 326, permanent magnet 328 and coil 330 are positioned on the opposite side of the pivot point 332 for the focus arm 302 than the OPU 324. The focus arm 302 moves in a direction perpendicular to the surface of the optical disk by rotation about shaft 334. The ends of shaft 334 are seated in cutout portions 336 and 338 formed in forward arms 340 and 342 of the tracking arm 300. The shaft 334 passes through an aperture 344 formed in the VCM block 326. Bearings 346 and 348 allow the focus arm 302 to pivot relative to the tracking arm 300. Rotational movement of the focus arm 302 about the shaft 334 is caused by alternating the current path in coil 330 which creates a magnet field that interacts

with the magnetic field of permanent magnet 328. Depending upon the direction of the current in coil 330, a torque is created relative to the field of the permanent magnet 328, causing the focus arm 302 to move towards or away from the surface of the optical disk.

5 The forward end of the focus arm 302 includes a pair of support arms 350 and 352, which hold and support the OPU 324 containing objective lens 356. A flex circuit 358 provides control signals to the OPU from appropriate microprocessors (not shown). A heat sink 360 can be included to assist dissipating heat generated by the laser (not shown) within the OPU 324.

10 While a few principal embodiments and certain alternative embodiments have been shown and described, it will be apparent that other modifications, alterations and variations may be made by and will occur to those skilled in the art to which this invention pertains, particularly upon consideration of the foregoing teachings. For example, the pivoting or rotation of the tracking arm and the focus arm may be provided by a ball bearing pivot, jewel bearing pivot, knife edge pivot, flexure pivot, bushing pivot, split band pivot or any type of
15 torsional pivot such as a torsional shear member pivot or other type of structure known to persons of skill in the art for achieving the desired relative movement. In addition, it would be understood that the location of any pivot point of the focus arm could be changed, as could the location and arrangement of the voice coil motor components. For example, either
20 the magnets or the coil could be stationary and the other move relative to the stationary components. Additionally, the respective VCM magnets and coils, on both the tracking arm and focus arm, can be alternatively positioned on the same side of the rotational axis as the optical pick up unit or on the opposite side of the rotational axis as the optical pick up unit

for the respective arm. In doing so, however, it should be understood that this relative close proximity of multiple voice coil motors may lead to cross coupling between the VCMs which can affect the performance of the tracking arm and focus arm. In the present invention, this problem has been addressed by optimizing the various return path structures as shown in the illustrated embodiments. In particular, for the specific embodiments disclosed herein, the return paths have been selected, in part, to assist in directing the magnetic fields to the appropriate VCM and away from the other VCM. It is therefore contemplated that the present invention is not limited to the embodiments shown and described and that any such modifications and other embodiments as incorporate those features which constitute the essential features of the invention are considered equivalents and within the true spirit and scope of the present invention.